Soil covers and capping monitoring techniques: an account of on-site experiences

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Abstract

At closure, some form of infiltration control is invariably required where reactive (e.g. acid-forming) materials are contained within tailings storage facilities (TSFs) and other waste rock landforms (WRDs). In this paper, an account is given of Newmont Australia's experiences with field techniques used to monitor moisture variations in soil covers at the Mt Leyshon, Woodcutters, Granites and Jundee mine sites. Critical comparison of the range of techniques available to assess cover systems is important in determining the most reliable and cost effective monitoring method and instrumentation to deliver sound and practical results useful for making management decisions.

For a number of years it has been common practice at Newmont's Australian operations to install a range of monitoring equipment into soil covers constructed on TSFs and WRDs, which often encapsulate material considered to be geochemically hostile. TSFs and WRDs at various sites have been instrumented. However the performance of this instrumentation, and the information it generates, has warranted scrutiny and consideration of the relative merits of this approach. Despite the common limitations of the techniques and instrumentation used, the Closure and Reclamation Group within Newmont Australia has endeavoured to maximise the value of the information obtained from the remaining instrumentation which still functions in a meaningful manner.

The information presented is intended to inform those who manage these types of facilities about important parameters and considerations involved in selecting methods to assess the effectiveness of cover systems.

Introduction

Assessment of the ability of TSF and WRD cover systems to restrict moisture 'break-through' below the cover is a priority in determining the success of the cover for infiltration control. Cover monitoring systems are often used to provide this information and thereby allow assessment of the cover's performance (Department of Industry, Tourism and Resources 2007). Soil-water storage cover systems, also known as 'store and release' covers, are intended to be integrated into ecosystems as a component of an unsaturated soil system subject to atmospheric forcing and whose long-term performance is directly linked to local climate conditions (O'Kane Consultants 2003). The objective is to restrict leaching of solutes or oxidation of acid-forming materials by minimising moisture and / or oxygen movement into the tailings or waste materials (Department of Industry, Tourism and Resources 2007).

From basic hydrological research on natural systems (e.g. catchments for water-supply purposes), it is well known that the water-balance of multi-hectare, vegetated landforms and landscapes defy accurate quantification (Campbell and Milligan 2008). Many environmental processes and patterns are scale dependant with the inherent complexities of scale complicating the use of results from small scale hydrological processes to predict or model processes at the whole-landform scale (Zhang et al. 2004). Since these same limitations apply to multi-hectare covers, the high spatial and temporal accuracy obtained via instrumentation with small sensing volumes, is undermined by the uncertainties associated with up-scaling from the test-plot scale, to the full-cover scale (Campbell 2004). Recognising the uncertainties of up-scaling, as it applies to both natural and constructed environments, management bodies responsible for the collection of such information need to ensure that the value of the information obtained is proportionate to the expense and demand on site resources, incurred by the cover monitoring programmes.

There is a need to critically appraise the necessity for, and benefits from, intensive cover-trial monitoring and associated numerical modelling, that is currently undertaken at a number of Australian mine sites. There is also a need for recognition of the limitations of the instrumentation, and level of technology development. Alternative methods which are often simpler and more direct, can have distinct advantages over more elaborate systems, achieving the same outcomes once the issues of up-scaling are taken into account (Campbell 2004). Agricultural research and technologies can provide information useful to the mining industry, where the concepts of preventing ‘leaky-landscapes’ in the WA Wheatbelt are comparable to development of vegetated store-release covers to prevent ‘leaky-landforms’ at mine sites (Campbell 2004). Both of these concepts tailor evapotranspiration to local weather conditions, such that deep-drainage rates are suitably constrained. However, care must be taken when adapting agricultural methods to mine based scenarios, due to the vast differences in the materials and landforms being monitored.

Professionals in many disciplines aspire to reduce problems to objective numbers or simple indicators. Hence simple processes are often developed for what are in fact, very large, spatially and temporally complex systems. Although often a worthy aspiration, if the assumptions we use in building these processes are in any way flawed for the small scale indicators we select on a spatial scale, they are magnified exponentially when applied to the field setting. The small scale of area we use to generate data cannot be representative of systems which might be hundreds of hectares in size, have multi-dimensional layers of numerous types of waste in various patterns, characterised by variable control during material handling and placement, and subject to local material consolidation, resulting in infinitely variable micro and macro drainage topographies. When assessing cover and landform development, the extrapolation of results obtained from short-term monitoring (e.g. initial years following cover placement) to project performance over decades-to-centuries in the future is questionable at best, and may easily result in misleading predictions and unachievable expectations (Parsons *et al.* 2004).

Specific site conditions complicate our ability to quantify these processes. Surface ripping treatments, structure and patchiness of vegetation, termite nests, burrowing animals, fire, grazing and human disturbance subject the validity of monitoring systems to question and / or expensive interpretation that may be of little pragmatic value to decision making. Factors such as landform position, storm damage, and consolidation of landform materials in which the instruments are installed, must be duly considered along with the outlay associated with use of these techniques.

Use of high-resolution, state-of-the-art, vadose-zone moisture monitoring techniques can create unrealistic expectations within regulator and stakeholder groups of the capacity to understand and quantify cover performance. In some instances the very act of the instrumentation itself may undermine the integrity of the cover system (e.g. slumping of ground around large-scale lysimeters at the Woodcutters mine has created a sizeable water-gaining area on the covered WRD, and thus an area for ponding and enhanced recharge locally). Artefacts arising from instrumentation (e.g. by-pass flow along edges of access tubes installed for moisture sensors) may also occur thereby invalidating the expensive data sets produced from monitoring (see below).

Experience at a number of Newmont Australia's sites with monitoring instruments (e.g. lysimeters, moisture and matric-suction sensors, and weirs) are discussed below with relevance to installation, performance, outcomes and limitations.

Monitoring system instruments, intentions and limitations

Lysimeters

The use of lysimeters at the Woodcutters site in the Northern Territory and at the Mt Leyshon site in Queensland has met with limited success. Issues have arisen at the Woodcutters site with placement of the lysimeters in drainage areas of high flow feeding into a rock drain, which are not representative of the majority of the cover environment. One lysimeter has slumped to a degree that water ponds over it during winter, resulting in data that is only representative of localised ‘water-gaining’ areas rather than of overall cover performance. Remediation of this problem is not feasible as adding cover materials or raising the lysimeter position will change its function and generate unrepresentative data.

Initial design and installation of the Woodcutters lysimeters is also questionable. The top of the lysimeters, which were constructed using PVC water tanks, were distorted when installed, resulting in a non-cylindrical shape, making it difficult to calculate cross-sectional area as input into an infiltration formula. Two of the lysimeters at Woodcutters will be decommissioned, while two are still functioning (with drainage collected via tipping bucket mechanisms rather than pumps) although the accompanying EnviroSCAN® soil water sensors were struck by lightning and are not functioning.

At Mt Leyshon, the original set of four lysimeters completely failed and were abandoned, then replaced with new lysimeters which were trapezoidal in shape. The trapezoid shape results in a funnelling and concentrating effect of soil water through the cover materials within the lysimeters, resulting in drainage estimates that are biased on the high side. The tipping bucket devices installed to collect drainage did not have the capacity to keep up with the flow, resulting in drainage flow that was under-estimated. Photographic evidence of the construction of these lysimeters indicates that the construction method of the material within the lysimeter was different to that carried out on the main cover. The lysimeter material was compacted with an excavator roller, whilst the material surrounding the lysimeter was traffic compacted in most instances.

Appropriate location of lysimeters is paramount to allow assessment of the hydrological behaviour of target landscape units, such as water-shedding or water-gaining areas, in order to characterise the full-scale multi-hectare cover system. As the materials inevitably consolidate in and around the lysimeters, their shape and accurate function are compromised. Differences in compaction methods and the resulting material density are inevitable when installing lysimeters, despite due care at installation. The question therefore remains as to what extent such differences manifest themselves in terms of contrasting hydraulic properties of the profiles within and outside the lysimeter.

EnviroSCAN® soil-moisture, matric suction sensors and diviners

Automated EnviroSCAN® soil-moisture and matric suction sensors have been installed at Newmont's Mt Leyshon, Woodcutters, Granites and Jundee sites. These methods produce real time monitoring of soil-moisture dynamics at a high spatial and temporal resolution at the point or plot scale, to assess the ability of covers to buffer rainfall inputs, and minimise recharge of the underlying mine wastes or process tailings. This technology was originally developed for agricultural scenarios, to continuously log soil moisture content at different depths over time.

The cost of such instrumentation is significant. At the Woodcutters site, four nests of EnviroSCAN® units were installed, each with 15 capacitance-type sensors, totalling $18,000. This cost does not include the mounting stem and CPU for each nest, time and resources for installation, calibration and data upload. Once installed, calibration is required for each of the EnviroSCAN® sensors to obtain material-specific calibration curves at additional expense. The manufacturer-supplied calibrations relate to finely textured soils, and cannot be directly applied to regolith materials containing high proportions of gravel or larger coarse fragments (Campbell 2004). Once installed and calibrated, maintenance issues may arise as the EnviroSCAN® tubes move with consolidation, making their retrieval impossible if there is a technical problem. In such a case, the overall monitoring effort is severely compromised. All four EnviroSCAN® sets at the Woodcutters site have failed, two in a slumped area and two disabled by lightning.

As with lysimeters, the issue of scale is again relevant, with the small sensing volume of the 'fringe-capacitance' technique (mm to cm scale from the exterior to the PVC access tube) meaning that the point-scale extrapolation challenge is even greater than that of lysimeters. If the point of monitoring is generally representative of the cover and the cover is fairly uniform, both vertically and laterally, then this resolution of monitoring can be appropriate. This level of monitoring has a high associated cost, given requirements for installation, calibration, routine download and data management, which may not be fully appreciated or justified.

Approximately 30 access tubes (for Diviner® 2000 capacitance sensors) are used at the Woodcutters site, with 8 at Mt Leyshon, and some in place at the Granites and Jundee. Like EnviroSCAN® sensors and lysimeters, diviners are used to gain an understanding of water penetration though the cover materials, although diviners are not automated and require manual data capture. Diviner rods are inserted into access tubes, which are also subject to the effects of material compaction around the tubes and consolidation over time. Tubes have been known to break during construction or consolidation of waste materials, which can cause difficulties inserting and retrieving the diviner rods. The access tubes themselves can promote preferential flow of water along the outer surface of the tubes, changing local hydrologic patterns in their location, and resulting in unrepresentative data.

At the Jundee site, access tubes for moisture monitoring were installed in the centre of small evaporation basins as part of an elaborate field cover-trial programme. Through inadequate design and appreciation of the realities of atmospheric forcing within the Australian arid zone, the tops of the access tubes become submerged beneath ponded water generated from major summer storms. Bypass flow down the sides of the access tubes results in spuriously high moisture contents in the cover profiles following major storms. Such high moisture contents are simply an artefact of the instrumentation approach employed. Furthermore, such technique artefacts, and ensuing invalid monitoring data, were not identified when collating and analysing the monitoring information obtained. Accordingly, interpretation of the monitoring results, as outlined in consultants reports, has been incorrect and has led to quite bizarre explanations of unsaturated-water flow in the cover profiles. Through a combination of inadequate design, and lack of quality time given to analysis of the 'raw' monitoring data, it is likely that only limited information can be salvaged from the field-trial covers which will assist management decision making for closure of the TSFs at Jundee.

Weirs

Weirs were installed at three locations at Woodcutters to provide information on the water balance, through assessing rainfall runoff on the waste landforms. However, as there was only one weir on the WRD and three drop structures, the proportion of the top drainage through the weir could only ever be roughly estimated. The weirs were subject to sediment build-up below the measuring mechanism, which needs to be cleared after every storm to ensure the weir continues to function accurately. This level of maintenance is not feasible in tropical environments subject to high intensity and frequent storm events which can produce high sediment loads in storm runoff.

The concentration of run off from the Woodcutters WRD via concrete wings through the weir, began to cause significant erosion and undermining of the rock drains. This weir was subsequently removed to preserve the integrity of the WRD. Two weirs intended to measure runoff collected from the WRD in formal drains, before transfer to Woodcutters Creek, also suffered from sediment build up and invalid data results. In addition, the weirs were not of a sufficient size to account for total flow, hence the water would back up and bypass the weirs, further compromising the accuracy of the readings. The run-off measured in these weirs sometimes included surface waters that did not originate from the WRD but rather from surrounding areas, whilst some of the water originating from the WRD overtopped the perimeter drain and was not collected through the weir system.

If the information provided by weirs is considered to be of value to justify the expense of appropriate design and installation, then weirs need to be designed with the capacity to receive the level of runoff that may occur and to maintain functionality in high sediment-load environments. Weir drainage systems need to collect all intended runoff and exclude runoff from surrounding areas. As with all monitoring systems, appropriate location of weirs is needed to provide representative data of the runoff expected from a target area, with due consideration of the potentially negative effects of concentrating flow on landform surfaces.

Alternative instrumentation

Newmont is currently investigating a range of alternate instruments available for cover performance monitoring. *In situ* opportunistic field infiltrometer programs over representative locations of completed covers may provide an option, where ring-infiltrometers of 0.5 m diameter could be used in engineered water-gaining areas, where water may pond for up to several weeks from major inundations, or floors of rip lines in ‘flat’ areas which makeup the majority of the covers on top of waste-dumps. Manual tracking of wetting-front penetration from major wet-spells (30 to 50+ mm of rainfall) using gypsum blocks or other low-cost devices for measuring either water content or matric suction may provide a simple approach which is especially suited to sites where the combination of climate and texture of cover materials, produces a low-leaching regime (e.g. oxide-regoliths derived from lateritic profiles, and rainfall seasonality within the WA Goldfields).

Aside from instrumentation for cover performance monitoring, weather station data is consistently used and is of undeniable value for assessing site specific climatic conditions that ultimately determine the performance of cover systems, and their ability to manage the anticipated levels of rainfall, runoff, infiltration and evaporation they may encounter.

Consideration of site specific conditions

A range of climatic conditions are experienced at mine sites across Australia, from tropical, to arid and temperate climates, with experiences at mine sites from one climatic region often not directly comparable to another. As there are limitations to predicting how soil covers will perform from natural soil processes (Bryan 2000), assessment of site specific needs and risks, which are often dictated by climate as well as specific material properties, will indicate the approach that needs to be taken in cover studies and modelling, as well as in the design of the covers system itself (Campbell 2008). It is absolutely critical that any development of a conceptual model for infiltration control, as a function of the cover system, is appropriate for the climate and the biophysical setting of the mine site (Department of Industry, Tourism and Resources 2007). This applies to both water-limited arid environments (e.g. WA Goldfields), and seasonally well-watered semi-tropical environments (e.g. northern Australia).

Landform design is particularly relevant to both the installation and intended outcome of any monitoring techniques. Inadequate landform drainage design causes difficulty when nominating representative locations on the landform for monitoring. Furthermore, unnecessary monitoring can be avoided if site specific conditions, such as the basic determination of the physical and geochemical characteristics of the materials within the landform, are given due consideration in the initial closure planning stage of cover and monitoring system development, with no single approach that is directly applicable to all waste landforms (Russell 2008).

An added complication of generating site-specific calibrations is the inevitable variation in the physicochemical character of the soil / regolith materials sourced for covering works. The resulting spatial variation in physicochemical properties, even for a given geomorphic setting (e.g. water-gaining and water-shedding areas) calls into question the concept of using point-scale plots for intensive monitoring of moisture dynamics (e.g. sensors every decimetre which are measured every hour). Macropores, vegetation, preferential flowpaths and heterogenous materials all contribute to spatial variability in a cover system and can greatly influence soil hydrological response during storm events, the processes and impacts of which are very difficult to account for when using detailed monitoring and modelling (Bryan 2000; Campbell 2004). Consolidation of deposited materials can result in cracks and slumping and the encouragement of preferential flow paths, significantly increasing infiltration (Department of Industry, Tourism and Resources 2007).

In the Australian arid zone, changes in soil-temperature can be another complicating factor if not appropriately considered in monitoring results, as moisture-tracking sensors are variably dependant on temperature (Campbell 2007; Campbell 2004). There is field evidence that, under the conditions of the Australian interior, moisture contents recorded by the EnviroSCAN® sensors (and likely capacitance-sensors generally) may be appreciably biased on the high side in dry soils / covers, due to a soil-temperature effects. This can give the impression that there is less pore-space available for water retention in the cover for summer storms, and thereby erroneously imply that thicker covers are necessary.

Recommendations

Experiences with cover monitoring systems has highlighted the importance of investigating the likely behaviour of the cover systems both *before and after* placement. Before cover placement, potential cover profiles may be investigated using laboratory based column tests (e.g. Outback Ecology, 2008), in addition to standard material characterisation, which are applicable to characterise the performance of ‘loose’ cover designs given that tightly-compacted covers are now largely not used. After placement, periodic assessment of infiltration parameters using infiltrometers on undisturbed, representative sections of the cover system, excavations in representative locations to assess the level of cover integrity, plant rooting patterns and the final cover profile structure, would provide sound data of greater benefit to management of these sites. Ultimately, investigation of material behaviour prior to final cover design and use in cover systems can minimise future maintenance and re-working costs, and allows for cover designs to be based on a solid database of site specific information (Campbell 2004).

As cover systems are generally intended to be revegetated, the complications of vegetation growth and resulting evapotranspiration on soil moisture dynamics can be assessed through a simple process of observations to provide information that the results from high-resolution soil-moisture content and matrix suction sensors cannot. Lysimeters are not recommended in light of Newmont’s experiences, and indeed there is evidence in the literature that the scale of lysimeter currently used is inadequate. Wilson (2008) suggests that that only large scale lysimeter studies, both physically (10 – 20 m or larger) and temporally over long periods of time (10 years or longer) provide useful results in their intended environments, as it is impossible to generate realistic results in the short term.

Conclusions

The majority of cover monitoring techniques use instrumentation that was originally designed for use in agricultural scenarios, not in reconstructed landscapes, where entirely different materials can be encountered, in reconstructed profiles that inevitably consolidate, and are likely to compromise the functionality of the installed equipment. Much of the instrumentation on Newmont Australia's closed sites has been decommissioned through becoming debilitated, though persistence with some monitoring efforts is ongoing to allow comparison with other techniques.

It has become clear that, in the past, there has been limited appreciation of the significant shortfall between the true value of the information obtained, and the total cost in time, resources and expenditure needed to implement real time monitoring programmes involving intensive instrumentation. Cover system monitoring and modelling is a prolonged process that can be very expensive, and the costs of this approach must be considered in perspective of the design of store-release covers for specific climates (Campbell 2004).

Real time monitoring is an attractive option for those wanting objective measures, state-of-the-art technologies, or purely to conduct fundamental research. However, in hydrological terms at the multi-hectare scale for rehabilitated TSFs and WRDs, it is only possible to broadly estimate the components of the water balance assessment for the landforms (Campbell 2004). Furthermore, when infiltration control is necessary, the infiltration control approach adopted in the design phase should be tailored to both the site's climate, and the physical properties (especially water-retentive and water-transmissive properties) of the soil, regolith or bedrock materials earmarked for the covering works.

Newmont Australia's experiences with cover monitoring technologies has revealed serious technique limitations and equipment reliability issues when they are applied to cover profiles, which are initially unconsolidated, under the harsh conditions of the Australian interior. Ultimately, it is undesirable to install equipment that proves inaccurate or unreliable, to run into additional maintenance expenditure or to produce artefacts from abandonment of equipment. The usefulness of the information generated from these techniques must be considered, as it is unlikely that management responses, such as expensive remedial earthworks, could be based solely on the results of point-scale monitoring in a small number of plots if there is no sign of significant off-site impact. Walkover surveys and inspections are a more direct method of identifying areas where the cover system is compromised (e.g. enhanced infiltration from slumping or piping), and in high-leaching situations groundwater monitoring may prove a sensitive means of cover performance assessment, for example as governed by the nature and flux of solutes, and lag times of infiltration and seepage.

Where there is a need for covers to control infiltration, there is clearly a need to have means of gauging how well infiltration is being controlled. There exists a range of high-tech gadgetry that, under conditions ideal for measurement, allows highly accurate determination of moisture variations in soils and other porous media. However, it is by no means a given that the physicochemical conditions required for such high accuracy are satisfied in soil cover systems on TSFs and WRDs. In addition, the issue of up-scaling from the test-plot scale (or 'instrumented-monolith’ (Campbell 2004)) remains. Since real-time monitoring and numerical modelling are demanding in terms of time, resources and budgets, careful thought needs to be given to what is undertaken in cover-design studies, so that the final outcomes reflect a balanced return-on-investment.

References

Bryan, R.B. (2000). Soil erodibility and processes of water erosion on hillslope. *Geomorphology*, **32**: 385-415.

Campbell, G. (2004). Store/release covers in the Australian outback: a review. Proceedings of the Australian Centre for Geomechanics Mine Closure Seminar – Towards Sustainable Outcomes. Perth, 5 – 6 August 2004. Australian Centre for Geomechanics, Perth.

Campbell, G. (2007). Isolation of reactive mine-wastes in the WA Goldfields: How arid-zone weathering and hydroecology simplify cover-design studies. Proceedings of the Australian Centre for Geomechanics Planning for Mine Closure Seminar. Perth, 14 – 15 June 2007. Australian Centre for Geomechanics, Perth.

Campbell, G. and Milligan, N. (2008). Modelling and Cover Design Studies. Proceedings of the Australian Centre for Geomechanics Planning for Stable Landforms Workshop, Perth, 4 March 2008. Australian Centre for Geomechanics, Perth.

Department of Industry, Tourism and Resources (2007). Managing Acid and Metalliferous Drainage; Leading Practise Sustainable Development Program for the Mining Industry. February 2007. Commonwealth of Australia.

O'Kane Consultants (2003). Proposed work scope for the Development of Tailings Storage Facility Cover System Designs at the Tanami Mines Joint Venture Tailings Storage Facilities, Newmont Australia, Tanami Operations. Unpublished scope for Newmont Australia, July 2003.

Parsons, A.J., Wainwright, J., Powell, D.M., Kaduk, J. and Brazier, R.E., (2004). A conceptual model for determining soil erosion by water. *Earth Surface Processes and Landforms*, **29**: 1293-1302.

Russell, M. (2008). Introduction and Overview. Proceedings of the Australian Centre for Geomechanics Planning for Stable Landforms Workshop, Perth 4 March 2008. Australian Centre for Geomechanics, Perth.

Wilson, W. (2008). Hydrology and covers for infiltration control. Proceedings of the Australian Centre for Geomechanics Planning for Stable Landforms Workshop, Perth, 4 March 2008. Australian Centre for Geomechanics, Perth.

Zhang, X., Drake, N.A., and Wainwright, J. (2004). Scaling Issues in Environmental Modelling. In: Wainwright, J. and Mulligan, M. (Editors), Environmental Modelling: Finding Simplicity in Complexity. John Wiley and Sons, Ltd. Chichester, pp. 319-334.